Changes in Arousal Levels Engendered by Externally Initiated Endogenous EM Fields

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Abstract — Current understanding of the reticular formation suggests a neural mechanism responsible for the involuntary regulation of cortical levels of arousal (sometimes referred to as levels of consciousness). The reticular formation manages rhythmic bursts of neurotransmitters (noradrealine, serotonin, and acetylcholine) to and from the cortex via 'projections' and thereby regulates cortical arousal. It may be possible to influence this neurotransmitter activity and levels of consciousness voluntarily through the introduction of an externally initiated endogenous low-level coherent electromagnetic (EM) field. If the frequency of this EM field is resonant with the oscillation of cholinergic ions within the nucleus reticularis, the intervening EM field will alter (or stabilize) the orbital motion of these ions. This in turn may modify membrane transport and production of acetylcholine and consequently result in changes in (or stabilization of) arousal states, attentional focus, and levels of awareness. This understanding may have implications in the enhancement of human performance as it relates to the control of generalized arousal levels such as the basic rest/activity cycle, sleep cycles, mood and motivational states, orienting, and vigilance.

Introduction

Newman (1997a,b) and references therein describe the extended reticular-thalamic activating system (ERTAS) and convincingly argue that this 'conscious system' is responsible for regulating generalized levels of arousal as well as individual explicit patterns of arousal. States of consciousness (representing one's first-person experience of the world) form as a synthesis of discrete, yet cortically distributed, levels of arousal combined with specific cognitive contents. Because consciousness is a synthesis of both arousal and content, changes in arousal levels inspired by the ERTAS are experienced as shifts in states of consciousness. Newman (1997a) writes, "This extended reticular-thalamic activating system (ERTAS) has been increasingly implicated in a variety of functions associated with consciousness, including: orienting to salient events in the outer world; dream (REM) sleep; the polymodal integration of sensory processes in the cortex (binding); selective attention and volition."

Electromagnetic (EM) fields exert measurable bioeffects in living organisms and specific frequencies reportedly have highly specific effects (Rubik et al., 1992). Studies have shown that weak EM fields affect brain electrical activity and memory processes in humans and laboratory animals (Bawin et al., 1996). EM fields have been shown to effect ion transport and adenosine triphosphate (ATP) splitting – a mechanism of stored energy release in living organisms, via changes in the activation of membrane enzymes (Zhalko-Tytarenko et al., 1997). Both processes vary with the frequency of the EM field and can be explained by the effects of the ionic currents

on ion binding at active sites of the enzyme (Zhalko-Tytarenko et al., 1997). This ionic activity appears to account for some of the effects low-level EM fields have on cells, as the transmembrane enzyme can convey the effect of an extracellular signal into the cell via ionic fluxes (Zhalko-Tytarenko et al., 1997). The introduction of an endogenous low-level coherent EM field into the reticular formation may be effective in inducing changes in arousal levels via similar ionic fluxes. The response to applied EM fields is highly frequency specific and low-level EM fields can produce highly specific biological responses (Rubik et al., 1992). Additionally, coherent EM fields produce substantially greater effects than incoherent signals on certain cellular pathways (Liovitz, Krause & Mullins, 1991 [cited in McCraty et al., 1997]).

The well-known diagnostic technique called electroencephalography (EEG) is based on the detection of endogenous EM fields produced in the central nervous system. Resonance interactions between endogenous EM fields within the central nervous system may provide a medium for *information* transfer and modification of central nervous system activity (Becker, 1990). Auditory stimuli which result in binaural beating initiate an endogenous low-level coherent EM field within the central nervous system as evidenced by the frequency-following response (Oster, 1973; Hink et al., 1980). Binaural beating has been associated with changes in levels of consciousness leading to sensory integration, relaxation, meditation, stress reduction, pain management, improved sleep, health care, enriched learning environments, enhanced memory, creativity, enhanced intuition, etc. (Atwater, 1997). The externally initiated endogenous EM field associated with binaural beating appears to regulate levels of consciousness by providing *information* to the ERTAS via ionic resonance.

The Extended Reticular-Thalamic Activating System

The endogenous EM fields known as brainwave patterns and their related arousal levels are said to be regulated by the reticular formation of the brain stimulating the thalamus and cortex. This extended reticular-thalamic activation system (ERTAS) controls a variety of functions associated with consciousness (Newman, 1997a,b). The word reticular means “net-like” and the neural reticular formation itself is a large, net-like diffuse area of the brainstem (Anch et al., 1988). The reticular activating system (RAS) interprets and reacts to *information* from internal stimuli, feelings, attitudes, and beliefs as well as external sensory stimuli by regulating arousal states, attentional focus, and level of awareness which are all crucial elements of consciousness (Empson, 1986; Tice & Steinberg, 1989). The reticular formation stimulates the thalamus and cortex, and controls attentiveness and level of arousal (Empson, 1986; Newman & Baars, 1993; Newman, 1977a,b). “It would seem that the basic mechanisms underlying consciousness are closely bound up with the brainstem reticular system . . .” (Henry, 1992). In the ERTAS model, cortico-thalamic projections transport rhythmic bursts of the neurotransmitter acetylcholine via the thalamus to the cortex. Lower portions of the reticular formation (the locus coeruleus and the raphe nuclei) provide the neurotransmitters noradrealine and serotonin via 'fountains' which largely bypass the thalamus on their way to the cortex (Newman, 1997a). It is the balance between these neurotransmitters that changes (or maintains) arousal levels (as measured by rhythmic EEG patterns throughout the cortex) and the ERTAS plays an active roll in regulating this balance.

The nucleus reticularis represents the heart of the ERTAS. It 'gates' neurotransmitter activity (*information*) to and from the cortex via cortico-thalamic projections and in conjunction with the intralaminar complex governs cortical EEG activity (Newman & Baars, 1993; Newman,

1977a,b). This 'gating' activity actually represents the interplay of inhibition and excitation as functions of the neurotransmitters involved. Rhythmic bursts of acetylcholine via cortico-thalamic projections either inhibit or excite areas of the cortex by neutralizing or enhancing the effects of noradrealine and serotonin coming to the cortex via 'fountains' from the locus coeruleus and the raphe nuclei. Within the ERTAS, *global activation* of the cortex for the regulation of customary arousal states, e.g., the basic rest/activity cycle, sleep cycles, mood and motivational states, orienting, vigilance, etc., comes primarily from projections from the nucleus reticularis and the intralaminar complex (Newman, 1997a).

Sensory input also alters ongoing arousal levels as a function of midbrain reticular activity. The concept of being conscious (aware) or unconscious (unaware) of sensory input is also a function of arousal level as regulated by the ERTAS as sensory data *compete* for our attention (Newman, 1997b). All of the major inputs from the major senses (relayed by the thalamus) must pass through 'gatelets' in the nucleus reticularis before they can reach the cortex (Newman, 1997b). "The major sensory modalities project to specific thalamic nuclei which, in turn, send topographically arranged projections to the primary visual, somatosensory (and auditory) areas" (Newman, 1997a). It is here, within the sensory tracks that externally initiated endogenous low-level coherent EM fields appear to regulate arousal states by providing *information* to the ERTAS via ionic resonance. There is evidence to suggest that the cell membrane may be one of the primary locations where applied EM fields act on a cell (Rubik et al., 1992). EM forces (alterations of ionic orbital motion) at the membrane's outer surface could modify ligand-receptor interactions (e.g., the binding of messenger chemicals such as hormones, neurotransmitters, etc., to specialized cell membrane molecules called receptors), which in turn would alter the state of large membrane molecules that play a role in controlling the cell's internal processes (Tenforde & Kaune, 1987 [cited in Rubik et al., 1992]), e.g., the production of neurotransmitters. Low-level coherent EM fields may affect neurocellular ionic oscillation within the cholinergic system or the 'gatelets' of the nucleus reticularis itself, and thereby alter the membrane transport and neurocellular production of acetylcholine. This would effectively alter arousal levels.

There are additional cortico-thalamic projections between the medial dorsal nucleus and the prefrontal cortex. This regulatory subsystem seems to play a part in the mediation of arousal states as they relate to internal process such as emotions, belief systems, and selective attention. These projections have also been implicated in working memory (Fuster, 1980; Goldman-Rakic, 1988 [both cited in Newman, 1997a,b]). It would appear that it is through this subsystem of cortico-thalamic projections that fears, worries, concerns, etc. influence arousal levels and one's first-person experience. This 'prefrontal' subsystem works in concert with the sensory and global-activation systems to provide a dynamic *thalamocortical circuit* that is found at virtually every area of the cortex (LaBerge 1995 [cited in Newman, 1997a,b]).

The norandrenergic and serotenergic neurons of the locus coeruleus and raphe nucleus are contiguous with the ERTAS and share important projections (Newman, 1997a). As explained above, these areas are extra-thalamic activation systems and serve as 'general activating systems' within the greater reticular formation (Newman, 1997a). Projections from these 'general activating systems' largely bypass the thalamus on their way to the cortex (Newman, 1997a). The reticulo-thalamic core (the thalamus and midbrain together) or ERTAS is mediated by cholinergic neurons which propagate the neurotransmitter acetylcholine (Scheibel, 1980; Macchi & Bentivoglio, 1986; Groenewengen & Berendse, 1994 [all cited in Newman, 1997a]). The 'gating' ability of the nucleus reticularis appears to be the arousal control mechanism of the ERTAS (for a detailed anatomical explanation see Newman, 1997a,b). This 'gating' activity

regulates the interplay of inhibition and excitation between noradrealine and serotonin from extra-thalamic activation systems and acetylcholine via cortico-thalamic projections from the ERTAS. Newman (1997a) writes, "*The thalamus is the principal source of extrinsic activation for nearly all of the neocortex*. [Newman's italics] Moreover, every region of the cortex that receives thalamic projections richly reciprocates them." The cortex *communicates* its arousal status back to the ERTAS via reciprocal projections. It is this *feedback* system that incites the ERTAS to adjust cortical arousal levels in global activation, in response to sensory input, and in concert with internal feelings, beliefs, memories, etc., by regulating ('gating') acetylcholine levels 'projected' via the thalamus to the cortex.

The brain automatically and actively regulates all body functions to maintain homeostasis – an internal equilibrium (Green & Green, 1977; Swann et al., 1982). In a natural and constant attempt to maintain a homeostasis of the elements of consciousness (see the above discussion of 'general activating systems'), the ERTAS actively monitors (via reciprocal projections) and continues the neural replication of ongoing levels of consciousness. If there is a reason to make an adjustment due to new *information* from internal sources or external sensory input the ERTAS responds appropriately. Sensory input which changes neurocellular ionic oscillation leading to the regulation of acetylcholine may influence the homeostasis of consciousness and provide access to propitious levels of consciousness not otherwise experienced.

The Effects of Endogenous EM Fields

Externally initiated endogenous low-level coherent EM fields within the ERTAS may be effective in inducing changes in arousal levels by way of inducing ionic fluxes in cholinergic neurons or the 'gatelets' of the nucleus reticularis. Cellular activity involves charged particles such as the common ions of sodium (Na+), calcium (Ca++) and potassium (K+) acting on or passing through the cell membrane (Becker, 1990). Since the cell membrane may be one of the primary locations where applied EM fields act on a cell (Rubik et al., 1992) and ionic activity is crucial to the function of the cell membrane, it seems relevant to consider the effect low-level coherent EM fields have on ions.

Charged particles or ions have a designated cyclic frequency determined by the ratio between the charge and the mass of the particle and by the strength of any existing EM field (e.g., the EM field of the earth). If another EM field is added that oscillates at exactly the same frequency (or harmonic thereto) as that of a particular ion, energy is transferred from the EM field to the charged particle (Becker, 1990). If the polarization of the added EM field is 180 degrees out of phase with the ion, the cyclic frequency of the ion slows. If the polarization is only slightly off, ionic spiraling will ensue. In the case of perfect polar alignment, the cyclic or orbital frequency of the ion increases. The concept here is that this well-understood ionic oscillation affects the binding of acetylcholine to cholinergic neurons (Scheibel, 1980; Macchi & Bentivoglio, 1986; Groenewengen & Berendse, 1994 [all cited in Newman, 1997a]) or the 'gatelets' of the nucleus reticularis and that by inducing changes in neurocellular ionic oscillation within the ERTAS, the production and membrane transport of acetylcholine may be affected (Tenforde & Kaune, 1987 [cited in Rubik et al., 1992]).

To initiate such changes in ionic oscillation a low-level coherent endogenous EM field can be externally initiated using an auditory phenomenon known as binaural beating. Perceived binaural beating indicates the presence of an endogenous low-level coherent EM field within the central nervous system as evidenced by the frequency-following response (Oster, 1973; Hink et

al., 1980). The low-level coherent EM field that accompanies auditory binaural beating appears to regulate arousal states by providing *information* and thereby inducing ionic fluxes in cholinergic neurons or the 'gatelets' of the nucleus reticularis.

The sensation of 'hearing' binaural beats occurs when two coherent sounds of nearly similar frequencies are presented one to each ear. The phase differences between these sounds engender an endogenous EM field at the frequency of the difference between the two (stereo left and right) auditory inputs. This phase difference normally provides directional information to the listener but when presented with stereo headphones or speakers the listener 'hears' a third sound called the binaural beat. The low-level coherent endogenous EM field (perceived as binaural beating) originates in the brainstem's superior olivary nucleus (Oster, 1973) and is neurologically routed to the reticular formation (Swann et al., 1982) and simultaneously volume conducted to the cortex where it can be objectively measured as a frequency-following response (Oster, 1973; Smith, Marsh & Brown, 1975; Marsh, Brown & Smith, 1975; Smith et al., 1978; Hink et al., 1980). This cortical EM field measurement was termed the "frequency-following response" because its period (frequency in cycles per second) corresponds to the frequency of the binaural-beat stimulus and the endogenous EM field present in the reticular formation (Smith, Marsh & Brown, 1975). The frequency-following response provides proof that the sensation of binaural beating is, in fact, a low-level coherent EM field within the central nervous system.

Binaural beats can easily be heard at the low frequencies that are characteristic of the EEG spectrum (Oster, 1973; Hink et al., 1980; Atwater, 1997) and the orbital frequencies of Ca++, Na+ and K+ ions (Becker, 1990). The existence of this externally initiated low-level coherent endogenous EM field within the central nervous system and specifically the reticular formation, suggests conditions that may facilitate alterations of levels of consciousness. There have been numerous anecdotal reports and a growing number of research efforts reporting changes in consciousness associated with binaural beats. The audio phenomenon known as binaural beating and corresponding endogenous low-level coherent EM fields have been associated with changes in arousal leading to sensory integration (Morris, 1990), alpha biofeedback (Foster, 1990), relaxation, meditation, stress reduction, pain management, improved sleep (Wilson, 1990; Rhodes, 1993), health care (Carter, 1993), enriched learning environments (Akenhead, 1993), enhanced memory (Kennerly, 1994), creativity (Hiew, 1995), treatment of children with developmental disabilities (Morris, 1996), the facilitation of attention (Guilfoyle & Carbone, 1996), peak and other exceptional experiences (Masluk, 1997), enhancement of hypnotizability (Brady, 1997), treatment of alcoholic depression (Waldkoetter & Sanders, 1997) and promotion of vigilance, performance, and mood (Lane et al., 1998).

Discussion

Some have referred to the apparent effect that binaural beats have on brainwave states as being the result of *stochastic resonance*, a nonlinear cooperative effect. This stochastic resonance model is inappropriate however because, as the model states, even though a small amount of noise added to a much larger signal can greatly increase the response to the signal, a weak signal added to a much larger noise will not generate a substantial added response (Adair, 1996). Binaural beats are not seen as 'a small amount of noise' being added to 'a much larger

signal' but as 'a weak signal' (a low-level coherent endogenous EM field) being added to 'a much larger noise' (ongoing brainwaves).

This paper does not report on research providing experimental scientific or statistical evidence of neurocellular ionic resonance as a mechanism of changes in arousal levels engendered by externally initiated low-level coherent endogenous EM fields (vis., binaural beats). Four decades of investigation have shown that exposure to binaural beating under appropriate circumstances can provide access to anomalous states of consciousness (Atwater, 1997). Several free-running EEG studies (Foster, 1990; Sadigh, 1990; Hiew, 1995, Brady, 1997, among others) suggest that binaural beating induces alterations in arousal states as measured by EEG. Because the RAS is responsible for regulating EEG (Swann et al., 1982; Empson, 1986; Newman & Baars, 1993; Newman, 1977a,b), these studies document measurable changes in RAS function during exposure to binaural beats. It is suggested herein that if the frequency of a binaural beat (seen as low-level coherent endogenous EM field) is resonant with the oscillation of cholinergic ions within the nucleus reticularis, energy is exchanged. It is further hypothesized that such an interchange alters the orbital motion of these ions and this in turn modifies the membrane transport and production of acetylcholine and consequently results in changes in arousal states. These suppositions are compatible with current knowledge of the reticular formation and suggest a neural mechanism for the voluntary regulation if cortical levels of arousal using of binaural beats. The implications in the enhancement of human performance as it relates to the control of generalized arousal levels such as the basic rest/activity cycle, sleep cycles, mood and motivational states, orienting and vigilance, etc., are intriguing. This paper encourages further research and the responsible application of existing technologies providing access to propitious states of consciousness.

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